Phosphorus, Sulfur, and Silicon and the Related Elements

ISSN: 1042-6507 (Print) 1563-5325 (Online) Journal homepage: https://www.tandfonline.com/loi/gpss20

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To cite this article: M. Benhaddad & F. Kerrour (2020) Modeling of low non-linearity and low confinement loss photonic crystal fiber by introducing asymmetric defect structures, Phosphorus, Sulfur, and Silicon and the Related Elements, 195:11, 957-959, DOI: 10.1080/10426507.2020.1804205

To link to this article: https://doi.org/10.1080/10426507.2020.1804205

Published online: 25 Sep 2020.

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PHOSPHORUS, SULFUR, AND SILICON AND THE RELATED ELEMENTS
2020, VOL. 195, NO. 11, 957–959
https://doi.org/10.1080/10426507.2020.1804205

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Modeling of low non-linearity and low confinement loss photonic crystal fiber by introducing asymmetric defect structures

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ABSTRACT

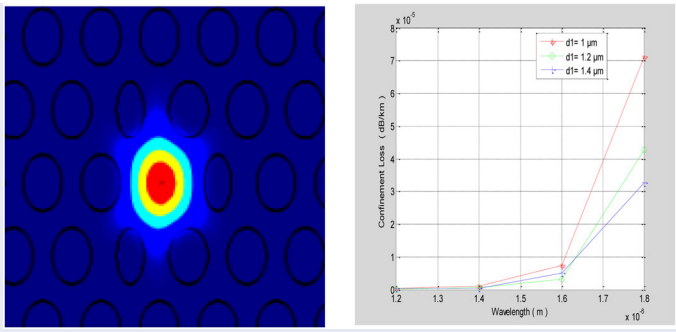
In this article, confinement loss in hexagonal lattice photonic crystal fiber has been investigated, by using COMSOL Multiphysics based on finite element method. The proposed structure consists of four circular air holes rings, where three circular air holes near the center are replaced by elliptical air holes, which have a major and minor diameter. The Confinement loss was studied in term of minor diameter and wavelength in the range of about 1200–1800 (nm). We realized that the rise of minor diameter lead to decreases of imaginary part of effective index and therefore the confinement loss reduces.

ARTICLE HISTORY

KEYWORDS

Photonic crystal fiber (PCF); finite element method (FEM); nonlinear coefficient

GRAPHICAL ABSTRACT



In recent years photonic crystal fibers (PCFs) also known as micro-structured fibers or holey fibers,[1–3] have attracted a great deal of attention in the optics community due to their unique waveguide properties which are not obtainable using conventional fibers, such as endlessly single mode, dispersion tailoring and high birefringence.[4,5] PCFs are consisting of matrix of air holes around a solid central core. Compared to conversional fibers, they can be designed with flexible structure and then excellent performances can be achieved. In this article, we have modeled a solid-core PCF using COMSOL Multiphysics based on finite element method (FEM).[6] The cross section of the proposed PCF structure is shown in Figure 1. It is composed of circular and elliptical air holes in the cladding arranged in a hexagonal array with lattice constant ($\Lambda = 3$ µm), The ellipse have a major diameter ($d_2 = 2$ µm) and three different values of minor diameter (d_1) of 1 µm, 1.2 µm, and 1.4 µm, the diameter of circular holes is ($d = 2$ µm).

The important optical properties like Confinement loss and nonlinear coefficient have been studied. The nonlinearity of PCF can be measured using the parameter (γ), termed as nonlinear coefficient. PCFs can have high non linearity because of its ability to confine high intensity of light.[6] The nonlinear coefficient of PCF can be calculated using following[7]:

$$\gamma = \frac{2\pi n_2}{\lambda\ A_{\text{eff}}}\left[\text{w}^{-1}\text{m}^{-1}\right] \tag{1}$$

The confinement loss of PCF is the leakage of power from core to the cladding and is deduced from the imaginary part of the effective modal index which is found through simulation. It is calculated using following Eq. (2)[8]:

$$Lc = \frac{40\pi}{\ln(10)\lambda}\, im(n_{eff}) \times 10^3 \left[\frac{\text{dB}}{\text{km}}\right] \tag{2}$$

where $im(n_{\text{eff}})$ is the imaginary part of the effective refractive index.

The designed PCF structure is simulated and three-dimensional view of typical mode pattern in the inner core of PCF is shown in Figure 2.

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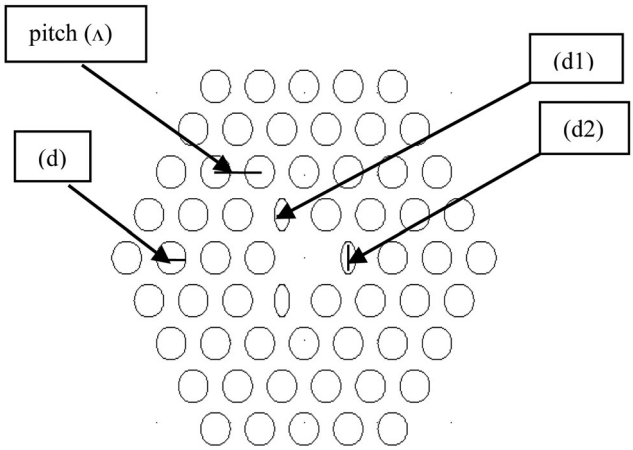

Figure 1. Geometry of solid-core photonic crystal fiber.

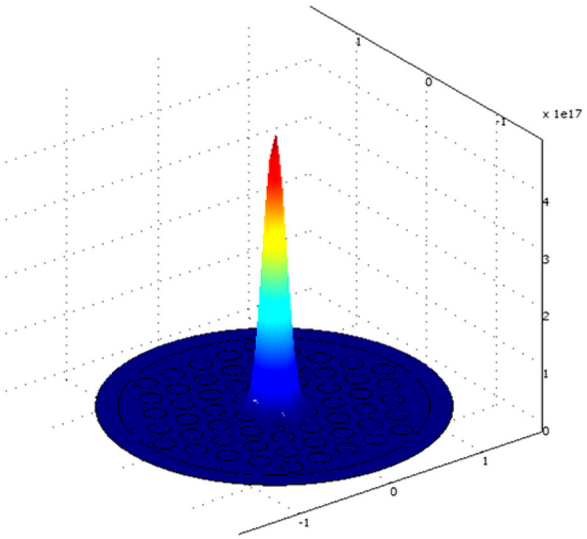

Figure 2. Typical mode pattern in the inner core of (PCF).

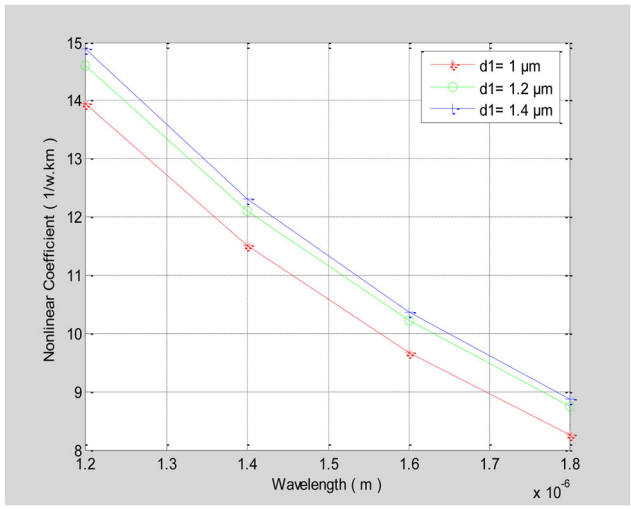

Figure 3. Plot of nonlinear coefficient vs. wavelength.

The variation of different parameters of proposed PCF like nonlinearity and confinement loss with respect to wavelength and minor diameter (d_1) is analyzed and plotted.

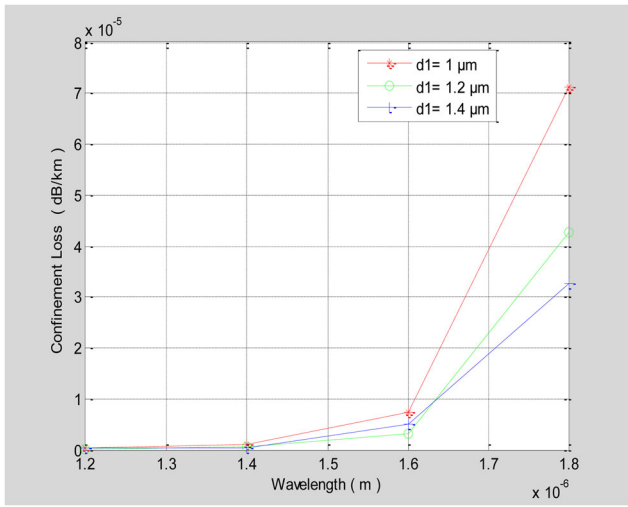

Figure 4. Plot of confinement loss vs. wavelength.

The variation of nonlinear coefficient, with respect to wavelength for three different values of (d_1) is shown in Figure 3. It can be seen that nonlinear coefficient decreases as wavelength increases,[9,10] and minor diameter (d_1) decreases. From the results a maximum of 14.8828 (1/W km) is observed at 1200 nm and (d_1 = 1.4 μm), although minimum of 8.2469 (1/W km) is observed at 1800 nm, and (d_1 =1 μm).

The variation of confinement loss, with respect to wavelength for three different values of (d_1) is shown in Figure 4. It can be seen that confinement loss increases as wavelength increases,[11,12] and minor diameter (d_1) decreases. A maximum of 7.122e-5(dB/km) is observed at 1800 nm, and (d_1 = 1 μm), moreover a minimum of 2.0917e-7(dB/km) is observed at 1200 (nm) and (d_1 = 1.4 μm).

In this article, four ring hexagonal solid core PCF, with elliptical and circular air holes in cladding has been designed for three different values of minor diameter (d_1) using COMSOL Multiphysics based on FEM. The optical nonlinearity of these PCFs has been investigated. As the minor diameter decreases, core diameter increases and so as the optical energy leakage increases, nonlinearity decreases. The nonlinear coefficient of the designed PCF is less than 8.25 (1/W km) for d_1 = 1 μm, d_2 = 2 μm, d = 2 μm, and Λ = 3 μm. The variation of confinement loss with respect to wavelength for three different values of minor diameter is also investigated. The results shows that the proposed PCF exhibit a very low confinement loss of 2.09e-7 (dB/km) for PCF with minor diameter of 1.4 μm, d_2 = 2 μm, d = 2 μm, and Λ = 3 μm. These promising properties make our proposed PCF an excellent candidate for telecommunication application. In conclusion, the diameters of the 1st ring air-holes around the core in PCF cladding are the key parameters to control the nonlinearities and the confinement losses.

Disclosure statement

No potential conflict of interest was reported by the authors.

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